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Critical Literature Review
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Future Developments in Land Traverse Resupply Operations in Antarctica.

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Abstract (ca. 200 words):

Logistic support to inland bases and field parties in Antarctica consumes a large part of the budgets of National Antarctic Programmes. In recent years, significant cost savings have been made by replacing parts of some previously entirely air resupply operations with overland traverses. Since the first resupply of South Pole Station in 2005, incremental improvements to load carrying systems and sled design have improved the efficiency of traverses significantly by increasing the load each vehicle can pull. Autonomous vehicles carrying Ground Penetrating Radar systems and semi-autonomous tractor vehicles in the final stages of development and testing, offer the potential to further enhance the efficiency of traverses by improving route finding, increasing crew safety, and enabling crews to operate for longer periods, reducing mission length. The use of renewable energy sources to power small autonomous vehicles carrying Ground Penetrating Radar systems represents a further opportunity to improve the efficiency of traverses by reducing the amount fuel carried for use during the traverse. The use of renewable energy sources to power larger polar vehicles is being investigated, but reducing traverse fuel demand further by using of this type of technology in tractor vehicles is not likely in the short term.

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Aim

The purpose of this review is to examine developments in land traverse resupply operations in Antarctica that have, or could improve their efficiency and effectiveness. This will be achieved by examining; the factors that affect the efficiency of current land traverse operations; developments in equipment used in the operations that have already improved efficiency and; how those developments may be refined or enhanced.

Background

Conducting the scientific research required to address the 80 scientific questions identified during the recent Antarctic and Southern Ocean science horizon scan will require expanded year round access to the Antarctic continent (Kennicutt II et al., 2014). Supporting inland bases and field parties in Antarctica is a significant logistical challenge, one that consumes a significant part of the budgets of National Antarctic Programmes. For example, logistics consumes approximately 90% of the budget of the US Antarctic Programme (U.S. Antarctic Program Blue Ribbon Panel, 2012). Reducing support costs is a significant challenge that all Antarctic programmes will continue to face as they seek to address the 80 questions (Sanchez & Njaastad, 2013).

Current Traverse Operations

In recent years significant cost savings have been made by replacing parts of some previously entirely air resupply operations with overland traverses (U.S. Antarctic Program Blue Ribbon Panel, 2012). These include a large proportion of the resupply of South Pole station. This was first conducted by land traverse in 2005 (Weale & Lever, 2008). Compared to air resupply, land traverse operations “emit less 1% the pollutants, consume half the fuel and save $1.6million for each delivery of 320,000kg of fuel" (Lever & Weale, 2012).

Current land traverse operations generally comprise a lead route finding and proving vehicle equipped with Ground Penetrating Radar followed by a number of vehicles towing loads. These include loads of cargo and fuel for the destination, fuel for the vehicles on the operation and modules that support the crew, including living quarters and stores of maintenance equipment and spares (Hoffman & Voels, 2012). The crews generally comprise drivers for each vehicle, a radar operator, a small maintenance crew and field support staff member. For example, the South Pole Traverse in 2009/10 consisted of 9 vehicles crewed by 10 people (Thur, 2012). Travel is at speeds of between 8 and 11 kilometres per hour (Lever & Weale, 2012) and operations can be up to 45 days in duration (Weale & Lever, 2008).

Efficiency of Traverse Operations

The efficiency of current traverse operations is limited by a number of factors (Weale & Lever, 2008). The pulling power of the vehicles and the ease with which load carrying sleds can move over snow, limit the weight of cargo that each vehicles can tow and the speed at which they can travel. The amount of fuel required to be carried for use by the vehicles and the need to carry loads to support the crew during the traverse, limits the carrying capacity of the vehicles. The high stress working conditions and resulting strain on personnel during these operations mean that sufficient rest must be included in the traverse schedule. This limits the travel time and therefore distance that can be travelled each day. The difficulties associated with finding a safe route, particularly identifying and avoiding crevasses means there is a high probability of delays due to vehicles becoming imobilised. Delays may also be caused by mechanical failures due to the very challenging operating conditions (for example extremely low temperature) and the difficulties of conducting repairs under those conditions.

Since the first South Pole resupply operation, incremental improvements have been and continue to be made to traverses systems to address these issues. They have focused on; increasing the load that each vehicle can pull by improving sled mobility (Weale & Lever, 2008); reducing the number of crew required and/or increasing the time they can operate for by developing unmanned/autonomous vehicles (Date, Watanabe, Ishizawa & Chiba, 2012); improving route finding by using autonomous vehicles to detect crevasses (Lever et al., 2013a) and; using renewable energy to power vehicles to reduce the amount of fuel carried (Chen, Liang, Wang, Zhang, & Wu, 2014).

Improved Sled Mobility

The payload efficiency of a given tractor and sled configuration is measured as the weight of payload divided by the towing force (Lever & Weale, 2012). The force or pull generated by a tractor can be increased by increasing its engine size but this increases its weight, the amount it will sink and the likelihood of it becoming imobilised in soft snow. Since the tractors suitable for use in Antarctica, all have similar engine power and track width, attempts to improve the payload efficiency of traverse operations have focused on improving sled mobility (Weale & Lever, 2012).

The towing resistance of a sled depends upon; the sliding friction; snow compaction resistance and; plowing resistance. Of these sliding friction is the most significant factor. It is high at the start of a pull but drops over the first 30 minutes of travel as a layer of water forms on which the sled can travel develops due to friction (Weale & Lever, 2012). An optimal sled design is one that minimises weight, sliding friction and ground pressure; obtains uniform ground pressure; maximises the sled length and maximizes the thermal budget of the sled.

The first traverses used rigid steel sleds with narrow skis towed one behind the other. These had low contact area and were heavy resulting in high local pressure and had a high conductivity so quickly dissipated heat due to friction (Weale & Lever, 2012). These were inefficient, prone to digging in and resulted in a “slamming motion over peaks” (Lever & Weale, 2012). Initial attempts to improve their payload efficiency focused on configuring them differently so that travelled in pairs with their skis outside the pulling vehicles tyre tracks. This rendered small improvements but they remained highly inefficient (Lever & Weale, 2012).

To counter the problems of rigid sleds development shifted to designing flexible sleds with larger contact areas (Weale & Lever, 2008). As diesel comprised the largest load carried in the resupply to South Pole Station the first developments focused on sleds used to carry fuel Lightweight, high efficiency fuel sleds comprising flexible bladders strapped to high molecular weight polyethylene were developed. These cost 1/6th of the price of a steel sled ($15,000 per 11400 Litre version), weigh 1/10th of a steel sled and have significantly reduced towing resistance. They have enabled the amount of fuel delivered per towing tractor to be tripled (Lever & Weale 2012). Initially developed using tan coloured material, recent developments have seen use of a black fabric to increase solar heating of fuel. This has improved the thermal budget of the sled and further reduced the sleds sliding friction (Lever & Weale 2012).

Lightweight fuel bladders not only have high payload efficiency relative to steel sleds but have good strength and durability over large sastrugi and have successfully travelled over thousands of miles without rupturing. When first used bladders were found to crack after they have been emptied, folded for return transport and then stored for long periods of time over winter. But following testing which indicated this was tensile cracking due to stress relaxation in the polymer coating at tight folds. The way bladders are transported when empty and stored over winter has been changed (Lever & Weale 2012). Inflating the empty bladders with air when being transported empty and stored over winter following the 2013 South Pole Traverse has removed the problem. This has increased bladder life and reduced the labour cost of disassembling, storing and re-assembling the sleds each year (Lever, Weale, & Durell, 2014).

As fuel sleds have become more efficient so attention has turned to improving the performance of sleds for other loads. Like the first fuel sleds, these were made of steel, were heavy (5,000lb unladen weight for 20,000lb cargo), rigid, costly ($100,000 per sled) and had a poor towing performance (Lever, Song & Weale, 2014). Attempts to improve their mobility have (like the fuel sleds) focused on using a flexible plastic sled. Air Ride Cargo Sleds comprising a plastic sled overlain by air filled pontoons housed in fabric pouches that secure the sled to a cargo deck have been developed (Lever, Weale, & Durrell, 2014). These have worked well both in the Arctic and Antarctic.

During the 2012/13 South Pole Traverse, two sleds travelled 1000 miles with no leaks and worked well over sastrugi (Lever, Song & Weale, 2014). The material used for the fabric pouches though, was stiff at low temperatures so outdoor assembly was difficult and cracks and tears developed as it flexed over rough ground. Subsequent tests have identified a more durable and flexible polymer-coated fabrics material for use in the next pouches. These will be used in subsequent trials (Lever, Weale, & Durrell, 2014). Sled designs continue to evolve with modular sleds that can carry both fuel and cargo being developed and tested in Greenland in 2014 (Polar Field Services, 2014). Further research and development will focus on better understanding stresses on payloads in order to refine the design of and develop sleds for the transportation of sensitive and out of gauge equipment (Lever, Song & Weale, 2014).

Autonomous Vehicles

The size of a crew and the physical and mental strain under which they operate are significant limiting factors on the efficiency of traverses. The use of autonomous vehicles offers considerable potential to increase traverse efficiency. An autonomous vehicle is one that can ”travel to a destination by itself”

(Date et al., 2012). To achieve this it needs “accurate positioning and orientation and ability to detect and avoid obstacles in its path” (Date et al., 2012). Development of these vehicles has focused on two areas; tractor units and route finding and proving vehicles equipped with Ground Penetrating Radar. It has included both semi-autonomous and completely autonomous vehicles.

The main aim of the development of autonomous tractor vehicles is to enable the number and duration of crew breaks to be reduced, thus increasing daily travel time and distance covered. This is achieved by retaining the same number of crew as are currently used so that 2 shifts can be established. The National Science Foundation believe that introducing this technology will enable them to double the number of South Pole traverses completed by 2016. This would save $2million dollars annually (National Science Foundation, 2012). To do so they are seeking to integrate commercial off the shelf products into the traverse fleet.

As part of operations to support science activities 1000km from Showa Station, Japan initiated a project to develop a traverse system comprising a manned multi task vehicle (based on a commercial off road vehicle with rubber tracks) followed by an unmanned tractor able to tow sledges “not able to be towed by multi task vehicle” (Date et al., 2012). This semi-autonomous system is designed to travel 1000km over 3 weeks towing loads up to 10 tons. The unmanned vehicle is equipped with a Global Positioning System (GPS) accurate to 0.2m and follows GPS waypoints transmitted wirelessly from the manned vehicle. This helps overcome some of the challenges of Antarctic travel including; navigation difficulties associated with lower GPS accuracy, lack of landmarks and slippage causing vehicle instability and inaccurate odometry. The vehicle also uses a front view camera to watch for a sign board on the last sled of the lead vehicle. This enables an emergency brake to be activated if required (Date et al., 2012). Tested in Japan, the system initially suffered from slippage between tracks and the surface which caused concern as it could cause unstable behaviour. Subsequent modifications have resulted in stable navigation and tracking of the unmanned vehicle being achieved to an error of not more than five metres (Date et al., 2012). These systems remain to be tested in Antarctica, however similar systems have developed and tested by the US Army in partnership with Lockheed Martin (McLeary, 2014).

Effective route finding and navigating is a key factor in determining the efficiency of a traverse. A critical component of this is detecting and avoiding hidden crevasses in order to avoid unnecessary delays or accidents. Crevasse detection is currently undertaken by a crew member in the lead vehicle of a traverse monitoring and interpreting data sent from a Ground Penetrating Radar (GPR) system mounted on the front of vehicle (Lever et al., 2013a).

This system poses a number of significant challenges which limit its effectiveness, and the efficiency of the traverse operation. Firstly, the operator has only a "2-3 second window to identify the approaching hazards and to tell the driver to stop" and secondly the "operator has to spend 8 to 12 hours focused on a screen" (Lever, Ray, Morlock, Burzynxki, & Williams, 2013b). This is highly stressful for both radar operator and vehicle driver (Lever et al., 2013a). Effectiveness is further limited by variations in crevasse signature depending on snow conditions and approach angle. Even with the best operator the probability of crossing an undetected crevasse remains high. Crevasses encountered at shallow angles pose the highest risk.

To address these problems, Lever et al., 2013a have developed an unmanned vehicle (polar rover) to conduct GPR surveys to detect under surface hazards in polar ice sheets. Navigating by GPS waypoints the vehicle is able to conduct surveys across pre-planned routes and wirelessly transmit the results to an operator. This allows it to be remotely programmed to carry out detailed searches should a possible hazard be identified. The system is able to; run for 3 hours or 16km on a set of batteries; to survive "-30C cold soaking and 10m/s blowing snow" and; be deployed in less time than is needed to warm up manual GPR vehicles. It is considered to have the potential to "improve safety of over snow travel by eliminating or complementing manual GPR surveys in hazardous regions" (Lever et al., 2013a).

Development of the system is now focused on resolving problems due to; reduced mobility in soft snow; its limited 3 hour battery life and; the need for its data to be interpreted by a human. Design changes being trailed include; introducing sensors to detect the start of traction loss; installing sensors and limits of pitch and roll angles to prevent overturning; developing in robot battery charging systems; battery packs that are easier to exchange (Lever et al., 2013a) and developing wind (Chen et al. 2014) and/or solar powered rovers (Lever & Ray, 2008).

Renewable Power Sources

Fuel carried for use in traverse vehicles or generators producing electricity to charge unmanned vehicles/rovers, represents a large part of the load carried by each traverse. Reducing the amount of fuel used during a traverse will significantly improve its efficiency either by enabling more loads to be carried for the destination or by removing the need to establish fuel depots on route such as those used on the Norwegian /US traverse of 2007/8 (Hoffman & Voels, 2012).

To extend the range of unmanned rovers designed to conduct science work or enable of unmanned GPR surveys experiments using both wind (Yao, 2014) and solar power (Lever & Ray, 2008) have been undertaken. Solar powered robots have been successfully developed that can carry a 20kg payload on a sled able to operate at -40 degrees Celsius (Lever et al., 2013b). Equipped with GPS navigation and iridium satellite communications these can conduct surveys at 3km per hour, are reliable, efficient and low cost. Susceptible to being blown over in winds over 20 metres per second, further development is focusing on refining their profile to reduce this risk.

Experiments with hybrid wind-solar powered robotic rovers have also been undertaken (Chen et al. 2014). Initial trials and resulting changes to the power management system have led to the development of a rover able to operate for almost 4 hours, but which consumes more energy than it generate. Future work will focus on improving wind turbine performance and improving the power management system before trials on snow and ice are conducted (Chen et al. 2014).

Development of vehicles powered by renewable energy sources have to date, focused on the smaller unmanned vehicles. Projects are underway to develop larger solar powered vehicles for use in polar conditions. For example, the Venturi Antarctica is an electric light tracked vehicle designed to be able to carry 1 ton of personnel and equipment over 150 km due to be trialed in 2015 (Dumitrache, 2010). It is considered by the manufacturers that this type of "transport and type of recharging should become widespread in the Antarctic" but no time frame for this occurring is given. There is no evidence that this technology has yet to be applied to the types of load pulling tractor vehicles used in traverses.

Conclusion

Since the resupply of the South Pole station in 2005 the efficiency of overland traverses has been increased by the development of flexible fuel sleds and Air Ride Cargo Sleds that enable greater loads to be pulled by each vehicle. These have also reduced the cost of traverse operations. Further efficiency gains may be achieved over the next 2 to 3 years by introducing semi-autonomous vehicles and autonomous GPR equipped rovers to traverses. These will enable crews to operate for longer and will reduce the risk of accidents and delays, increasing the number of operations able to be undertaken in each field season. The gains achieved by incorporating these systems may be further enhanced by the development of vehicles powered by renewable sources. Solar powered rovers are likely to be the first vehicle of this type able to be used in traverses. This would reduce the amount of fuel required to be transported on the traverse. Tractor vehicles that use renewable energy sources will take longer to develop and test, but would offer significant gains in efficiency by removing the need to transport fuel for use during the traverse.

References

Chen, J., Liang, J., Wang, T., Zhang, T. & Wu, Y. (2014). Design and Power Management of a Wind-Solar-Powered Polar Rover. *Journal of Ocean and Wind Energy*, 1 (2), 65 – 73.

Date, H., Watanabe, K., Ishizawa, K., & Chiba, M. (2012). Auto Guidance – Unmanned Tractors for Logistics. *Proceedings of the COMNAP Symposium 2012, Sustainable Solutions to Antarctic Challenges* (p37). Portland, Oregon, USA.

Dumitrache, A. (2010 October 01). 2010 Paris Auto Show: Venturi Antarctica. Retrieved from .http://www.autoevolution.com/news/2010-paris-auto-show-venturi-antarctica-live-photos-24981.html.

Hoffman, S.J., & Voels, S. A. (2012). *Antarctic Exploration Parallels for Future Human Planetary Exploration: The Role and Utility of Long Range, Long Duration Traverses*. Technical Report, Antarctic Exploration Parallels for Future Human Planetary Exploration Workshop; 4-5 Aug. 2009; Houston, TX; USA.

Kennicutt II, M.C., Chown, S.L., Cassano, J.J, Liggett, D., Peck, L.S., Massom,R.,…Sutherland, W.J. (2014). A roadmap for Antarctic and Southern Ocean science for the next two decades and beyond. *Antarctic Science*, 26 (1), 1 -16.

Lever, J.H., Ray, L.E. (2008) Revised solar-power budget for Cool Robot polar science campaigns. *Cold Regions Science and Technology*, 52 (2), 177-190.

Lever, J, H, & Weale J C. (2012) High Efficiency fuel sleds for polar traverses. *Journal of Terramechanics*, 49 (3) 207 - 213.

Lever, J. H., Delaney, A. J., Ray, L. E., Trautman, E., Barna, L. A., & Burzynski, A. M. (2013a). *Autonomous GPR Surveys using the Polar Rover Yeti*. Journal of Field Robotics, 30 (2), 194-215.

Lever, J. H., Ray, L. E., Morlock, A. M., Burzynxki, A. M., & Williams, R. M. (2013b). *Over-Snow Rovers for Polar Science Campaigns. Presentation at Polar Technology Conference April 04 2013*. Retrieved from http://polarpower.org/PTC/list_2013.html.

Lever, J. H., Song, A., Weale, J. C., (2014). *Lightweight Cargo Sleds for Polar Traverses*. *Presentation at Polar Technology Conference April 17 2014*. Retrieved from http://polarpower.org/PTC/list_2014.html.

Lever, J. H., Weale, J. C. & Durell, G. (2014). *Low-Temperature Flex Durability of Fabrics for Polar Sleds*. Technical Report of U.S. Army Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory, 14 – 24.

Liu, J. (2014). Aerodynamic performance of multifunctional wind energy unit for long distance polar rover. 2014 IEEE International Conference on Mechatronics and Automation, 1883-1888.doi:10.1109/ICMA.2014.6885989

McLeary, P. (2014, May 13). *US Army's Unmanned Ground Vehicle Research Creeps Along*. Retrieved from http://www.defensenews.com/article/20140513/DEFREG02/305130031/US-Army-s-Unmanned-Ground-Vehicle-Research-Creeps-Along.

National Science Foundation (2012). *Response to: US Antarctic Program, Blue Ribbon Panel, More and Better Science in Antarctica Through Increased Logistic Effectiveness.* Washington DC, USA.

Polar Field Services (2014, May 16). GrIT update: the view from Summit. Retrieved from http://polarfield.com/blog/tag/polar-operations/.

Sanchez, R.A., Njaastad, B., (2013). Future Challenges in Environmental Management of National Antarctic Programs. In Tin, T., Liggett, D., Maher, P. T., & Lamers, M. *Antarctic futures: Human engagement with the Antarctic environment* (pp. 287 – 306). Dordrecht: Springer.

Thur, P., (2012). *Traversing in the Antarctic. Presentation from Polar Technology Conference April 05 2012*. Retrieved from http://www.polarpower.org/events/polar_technology_conferences/index.html.

US Antarctic Program, Blue Ribbon Panel. (2012). *More and Better Science in Antarctica Through Increased Logistic Effectiveness*. Washington DC, USA.

Weale, J., Lever, J.H. (2008). Innovations in over-snow cargo transport. *Cold Regions Science and Technology*, 52 (2), 166-176.

Weale, J. & Lever, J.H. (2012). *High Efficiency Polar Traverses*. *Presentation from Polar Technology Conference April 05 2012*. Retrieved from http://www.polarpower.org/events/polar_technology_conferences/index.html.

Yao, Z. (2014). Locomotivity of Antarctic roaming robot based on windsurfing and sled. *Journal of Chinese Association of Automation*, 36 (3), 369-374.